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Research Paper

Smart street light network based on IoT with real-time energy monitoring

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Abstract: Street lights are one of the biggest energy users in cities. This project shows an IoT-based smart street light method with real-time monitoring energy using ESP32. The goal is to use less power while still providing good lighting. An LDR sensor in the system tells the difference between day and night. The street lights stay off by themselves during the day. IR sensors can be utilized at night to find cars or people walking. When movement is detected nearby a certain street light, only that LED street light turns on, while the others stay off. This saves energy. The system also keeps an eye on the level of the voltage, which shows how much energy is being used, and shows the results on an LCD screen. The ESP32 microcontroller gives the system sophisticated control and IoT capabilities, making it good for smart city uses that need increased energy efficiency and control.

I. INTRODUCTION

The IoT-Based Street Light Monitoring system is designed to enhance urban lighting infrastructure by integrating automation, real-time monitoring, and remote control. Traditional street lighting systems often suffer from high energy consumption, inefficient maintenance, and lack of intelligent control, leading to increased costs and environmental impact. To address these challenges, this project leverages Internet of Things (IoT) technology, where an Arduino Uno microcontroller interfaces with multiple sensors to dynamically control streetlights

based on environmental conditions. A Light Dependent Resistor (LDR) sensor enables automatic adjustment of streetlights according to ambient light levels, while temperature and humidity sensors provide environmental monitoring. Relay modules control the switching of lights and charging points efficiently. For real-time monitoring and remote accessibility, an ESP8266 Wi-Fi module is integrated, enabling wireless communication with a cloud-based IoT platform. The system is powered by a 12V solar panel, ensuring sustainability and reducing reliance on conventional energy sources. An Android application is developed to allow users to monitor data and control streetlights remotely. By implementing smart technology, this project aims to reduce energy consumption, optimize operational efficiency, and enhance public safety. Accurate and efficient streetlight control contributes to smart city development, providing a scalable solution for urban infrastructure management. This study evaluates the system's performance based on key factors like energy efficiency, cost reduction, reliability, and remote accessibility, offering insights into the effectiveness of IoT-based smart street lighting solutions.

II. RELATED WORK

"IoT Based Smart Street Lighting System"

Sharma, R.

This paper presents an IoT-enabled street lighting system that integrates sensors and microcontrollers to reduce energy consumption. The authors highlight the importance of automation in urban infrastructure and propose a system that switches lights ON only when motion is detected. The study concludes that IoT-based systems are cost-effective, scalable, and suitable for smart city applications.

"Energy Efficient Street Lights using IoT"

Patel, A.

Patel's research focuses on energy-efficient street lighting solutions using IoT. The system employs LDR and IR sensors to control street lights based on environmental conditions and human presence. The paper emphasizes reduced energy wastage and improved safety. The authors conclude that IoT-based systems significantly lower operational costs while ensuring reliable illumination.

"Smart City Lighting Solutions with ESP32"

Khan, S.

Khan's work introduces ESP32-based smart street lighting systems. The system integrates IoT platforms for real-time monitoring and control. The paper discusses scalability, reliability, and cost-effectiveness. The authors conclude that ESP32 provides efficient processing and wireless communication, making it ideal for smart city lighting solutions.

"Design of Intelligent Street Light Control System"

Mehta, P.

Mehta's paper details the design of intelligent street light systems using sensors and microcontrollers. The system automatically distinguishes between day and night and controls lights accordingly. The authors highlight the role of automation in reducing energy consumption. The study concludes that intelligent systems improve efficiency and sustainability in urban infrastructure.

"IoT Applications in Urban Energy Management"

Gupta, N.

Gupta's research explores IoT applications in urban energy management, including smart street lighting. The paper discusses sensor integration, real-time monitoring, and IoT connectivity. The authors emphasize sustainability and cost-effectiveness. The study concludes that IoT-enabled systems are vital for modern smart cities, reducing energy consumption and improving infrastructure reliability.

"Evaluation of Temperature Sensors for Detection of Heat Sources Using Additive Printing Method,"

Ju-Hun Ahn, Han-Na Kim, Jin Yeon Cho, Jeong Ho Kim.

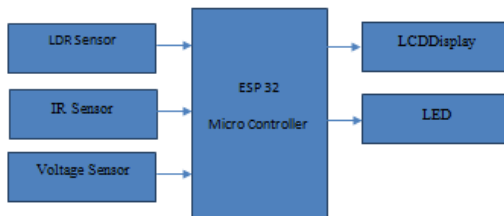
Electrohydrodynamic (EHD) inkjet printing is an efficient technique for printing multiple sensors in a multifaceted area. It can be applied to various fields according to the shape of the printing result and the algorithm employed. In this study, temperature sensors capable of detecting heat sources were fabricated. Inks suitable for EHD inkjet printing were produced, and optimal parameters for printing were determined. Printing was performed using the corresponding parameters, and various printing results were obtained. Furthermore, an experiment was conducted to confirm the temperature measurement characteristics of the results and the tolerance of the sensor. Grid-type sensors were fabricated based on the results, and the sensor characteristics were confirmed in an orthogonal form. Heat was applied to arbitrary positions. Resistance to changes due to heat was measured, and the location at which the heat was generated was detected by varying the change in resistance. Through this study, efficient heat control can be achieved, as the location of the heat source can be identified quickly.

III. IMPLEMENTATION

The proposed **IoT Based Smart Street Light System** uses an **ESP32 microcontroller** integrated with **LDR, IR sensors, LEDs, voltage sensing module, and LCD display**. The LDR detects ambient light intensity to differentiate between day and night conditions. During night time, the ESP32 continuously monitors IR sensors placed along the road. When an object such as a vehicle or pedestrian is detected by a specific IR sensor, only the corresponding LED street light is activated. The system also measures the **voltage level** using a

voltage sensing circuit and displays the real-time voltage data on the LCD. This intelligent control strategy ensures optimal lighting, reduced energy consumption, and improved system reliability.

Block Diagram



Working

The IoT-Based Smart Street Light System functions by intelligently controlling illumination and monitoring energy usage through the ESP32 microcontroller. An LDR sensor distinguishes between day and night, keeping lights OFF during daytime to save energy. At night, IR sensors detect the presence of vehicles or pedestrians, and only the corresponding LED street light is switched ON, while others remain OFF, reducing unnecessary power consumption. A voltage sensor continuously measures energy usage, with real-time values displayed on an LCD screen for monitoring. By integrating smart sensing, automated control, and IoT capability, this system ensures efficient street lighting, improved energy management, and suitability for smart city applications.

HARDWARE REQUIREMENTS

ESP-32

ESP32 is the SoC (System on Chip) microcontroller which has gained massive popularity recently. Whether the popularity of ESP32 grew because of the growth of IoT or whether IoT grew because of the introduction of ESP32 is debatable. If you know 10 people who have been part of the firmware development for any IoT device, chances are that 7–8 of them would have worked on ESP32 at some point. So what is the hype all about? Why has ESP32 become so popular so quickly? Let's find out.



Before we delve into the actual reasons for the popularity of ESP32, let's take a look at some of its important specifications. The specs listed below belong to the ESP32 WROOM 32 variant. –

- Integrated Crystal– 40 MHz
- Module Interfaces– UART, SPI, I2C, PWM, ADC, DAC, GPIO, pulse counter, capacitive touch sensor
- Integrated SPI flash– 4 MB
- ROM– 448 KB (for booting and core functions)
- SRAM– 520 KB
- Integrated Connectivity Protocols– WiFi, Bluetooth, BLE
- On-chip sensor– Hall sensor
- Operating temperature range– -40 – 85 degrees Celsius
- Operating Voltage– 3.3V
- Operating Current– 80 mA (average)

With the above specifications in front of you, it is very easy to decipher the reasons for ESP32's popularity. Consider the requirements an IoT device would have from its microcontroller (μ C). If you've gone through the previous chapter, you'd have realized that the major operational blocks of any IoT device are sensing, processing, storage, and transmitting. Therefore, to begin with, the μ C should be able to interface with a variety of sensors. It should support all the common communication protocols required for sensor interface: UART, I2C, SPI. It should have ADC and pulse counting capabilities. ESP32 fulfills all of these requirements. On top of that, it also can interface with capacitive touch sensors. Therefore, most common sensors can interface seamlessly with ESP32.

Secondly, the μ C should be able to perform basic processing of the incoming sensor data, sometimes at high speeds, and have sufficient memory to store the data. ESP32 has a max operating frequency of 40 MHz, which is sufficiently high. It has two cores,

allowing parallel processing, which is a further addition. Finally, its 520 KB SRAM is sufficiently large for processing a large array of data onboard. Many popular processes and transforms, like FFT, peak detection, RMS calculation, etc. can be performed onboard ESP32. On the storage front, ESP32 goes a step ahead of the conventional microcontrollers and provides a file system within the flash. Out of the 4 MB of onboard flash, by default, 1.5 MB is reserved as SPIFFS (SPI Flash File System). Think of it as a mini-SD Card that lies within the chip itself. You can not only store data, but also text files, images, HTML and CSS files, and a lot more within SPIFFS. People have displayed beautiful Webpages on WiFi servers created using ESP32, by storing HTML files within SPIFFS.

Finally, for transmitting data, ESP32 has integrated WiFi and Bluetooth stacks, which have proven to be a game-changer. No need to connect a separate module (like a GSM module or an LTE module) for testing cloud communication. Just have the ESP32 board and a running WiFi, and you can get started. ESP32 allows you to use WiFi in Access Point as well as Station Mode. While it supports TCP/IP, HTTP, MQTT, and other traditional communication protocols, it also supports HTTPS. Yep, you heard that right. It has a crypto-core or a crypto-accelerator, a dedicated piece of hardware whose job is to accelerate the encryption process. So you cannot only communicate with your web server, you can do so securely. BLE support is also critical for several applications. Of course, you can interface LTE or GSM or LoRa modules with ESP32. Therefore, on the 'transmitting data' front as well, ESP32 exceeds expectations.

With so many features, ESP32 would be costing a fortune, right? That's the best part. ESP32 dev modules cost in the ballpark of ₹ 500. Not only that, the chip dimensions are quite small (25 mm x 18 mm, including the antenna area), allowing its use in devices requiring a very small form factor.

One very big advantage with ESP32, which has aided its quick adoption and massive popularity, is the provision for programming the ESP32 within the Arduino IDE.

Now, I should point out here that Arduino is not the only IDE that helps you compile code for ESP32 and flash it into the microcontroller. There is ESP-IDF which is the official development framework for ESP32, which provides much more flexibility in terms of configuration options. However, it is hardly

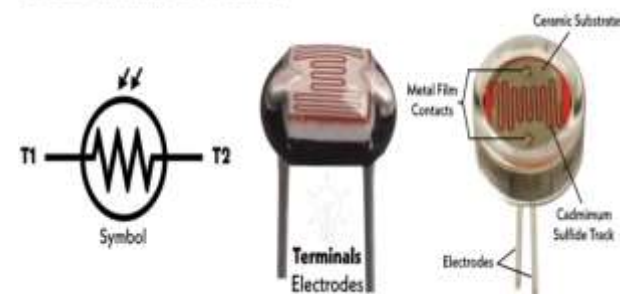
as intuitive and user-friendly as the Arduino IDE, and if you are starting out with ESP32, Arduino IDE is ideal to get your hands dirty. Also, with the number of supporting libraries built for ESP32 in Arduino, courtesy of the huge developer community, there's hardly any functionality of ESP32 which can't be realized with the Arduino IDE. ESP-IDF is more suitable for the more advanced and experienced programmers, who need to stretch ESP32 to its limits. If you are one of those, you are looking for the ESP-IDF Getting Started Guide. Others can follow along.

LDR SENSOR

LDR (Light dependent resistor) also known as **photocell**, **photoresistor** or **Photo Conductive Cell** is a light-sensitive resistor whose resistance varies with the intensity of light. It is a type of variable resistor whose resistance varies with the light. Its resistance varies inversely with the change in light intensity i.e. its resistance increases with a decrease in light intensity and decreases with an increase in light intensity.

It is a type of photo sensor that works on the principle of photoconductivity. Its electrical conductivity changes with the intensity of the falling light. Its resistance also depends on the frequency and wavelength of the incident light. Although its sensitivity depends on the design and Semiconductor material of the device.

*LDR is also known as Photocell & Photoresistor



It is used in light sensing circuit that operates based on light and dark conditions such as street lights, solar panels, solar tracker, etc.

IR SENSOR

The IR sensor or infrared sensor is one kind of electronic component, used to detect specific characteristics in its surroundings through emitting or

detecting IR radiation. These sensors can also be used to detect or measure the heat of a target and its motion. In many electronic devices, the IR sensor circuit is a very essential module. This kind of sensor is similar to human's visionary senses to detect obstacles.



IR Sensor

The sensor which simply measures IR radiation instead of emitting is called PIR or passive infrared. Generally in the IR spectrum, the radiation of all the targets radiation and some kind of thermal radiation are not visible to the eyes but can be sensed through IR sensors.

In this sensor, an IR LED is used as an emitter whereas the photodiode is used as a detector. Once an infrared light drops on the photodiode, the output voltage & resistance will be changed in proportion to the received IR light magnitude.

VOLTAGE SENSOR

This sensor is used to monitor, calculate and determine the voltage supply. This sensor can determine the AC or DC voltage level. The input of this sensor can be the voltage whereas the output is the switches, analog voltage signal, a current signal, an audible signal, etc. Some sensors provide sine waveforms or pulse waveforms like output & others can generate outputs like AM (Amplitude Modulation), PWM (Pulse Width Modulation) or FM (Frequency Modulation). The measurement of these sensors can depend on the voltage divider.



Voltage-sensor

This sensor includes input and output. The input side mainly includes two pins namely positive and negative pins. The two pins of the device can be connected to the positive & negative pins of the sensor. The device positive & negative pins can be connected to the positive & negative pins of the sensor. The output of this sensor mainly includes supply voltage (Vcc), ground (GND), analog o/p data

LCD

LCD is a flat display technology, stands for "Liquid Crystal Display," which is generally used in computer monitors, instrument panels, cell phones, digital cameras, TVs, laptops, tablets, and calculators. It is a thin display device that offers support for large resolutions and better picture quality. The older CRT display technology has replaced by LCDs, and new display technologies like OLEDs have started to replace LCDs. An LCD display is most commonly found with Dell laptop computers and is available as an active-matrix, passive-matrix, or dual-scan display. The picture is an example of an LCD computer monitor.

The Liquid Crystal library allows you to control LCD displays that are compatible with the Hitachi HD44780 driver. There are many of them out there, and you can usually tell them by the 16-pin interface.



Output of the sketch on a 16x2 LCD

The LCDs have a parallel interface, meaning that the microcontroller has to manipulate several interface pins at once to control the display. The interface consists of the following pins:

- A register select (RS) pin that controls where in the LCD's memory you're writing data to. You can select either the data register, which holds what goes on the screen, or an instruction register, which is

where the LCD's controller looks for instructions on what to do next.

- A Read/Write (R/W) pin that selects reading mode or writing mode
- An Enable pin that enables writing to the registers
- 8 data pins (D0 -D7). The states of these pins (high or low) are the bits that you're writing to a register when you write, or the values you're reading when you read.

There's also a display contrast pin (Vo), power supply pins (+5V and GND) and LED Backlight (Bklt+ and Bklt-) pins that you can use to power the LCD, control the display contrast, and turn on and off the LED backlight, respectively.

The process of controlling the display involves putting the data that form the image of what you want to display into the data registers, then putting instructions in the instruction register. The Liquid Crystal Library simplifies this for you so you don't need to know the low-level instructions.

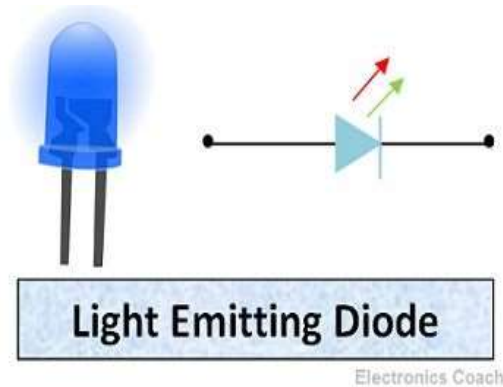
The Hitachi-compatible LCDs can be controlled in two modes: 4-bit or 8-bit. The 4-bit mode requires seven I/O pins from the Arduino, while the 8-bit mode requires 11 pins. For displaying text on the screen, you can do most everything in 4-bit mode, so example shows how to control a 16x2 LCD in 4-bit mode.

LED

LED (Light Emitting Diode) is an optoelectronic device which works on the principle of electro-luminescence. Electro-luminescence is the property of the material to convert electrical energy into light energy and later it radiates this light energy. In the same way, the semiconductor in LED emits light under the influence of electric field.

The symbol of LED is formed by merging the symbol of P-N Junction diode and outward arrows. These outward arrows symbolise the light radiated by the light emitting diode.

Now, the question arises how the semiconductor material in LED emits light? The answer to this question lies in the construction and working of LED. The symbol of LED is described in the diagram below, the same symbol is used in electronics circuits.



IV. RESULT ANALYSIS

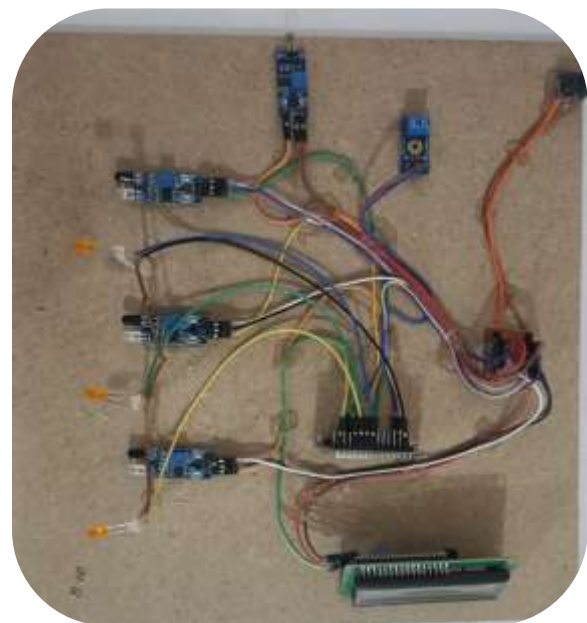


Fig1: project kit

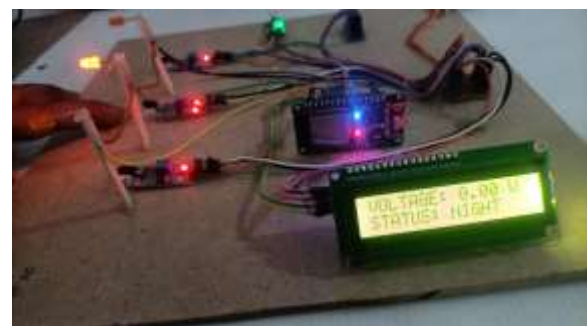


Fig2: status

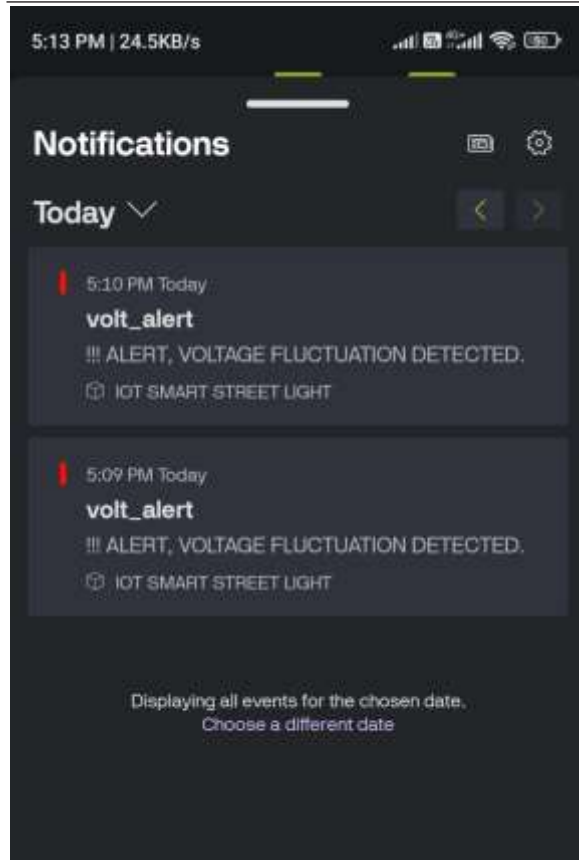


Fig3: if any suspicious actions , notifications to mobile

V. CONCLUSION

The IoT Based Smart Street Light System with Real-Time Energy Monitoring demonstrates how embedded systems and IoT can revolutionize urban energy management. By integrating LDR and IR sensors with ESP32, the system ensures efficient illumination, reduced energy consumption, and improved safety. Its scalability and cost-effectiveness make it suitable for smart city applications, contributing to sustainable urban development and environmental conservation.

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